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Optimum levels of work in process (WIP) for navy field contracting organizations: a decision rule

Qua, John F.

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THESIS

OPTIMUM LEVELS OF WORK IN PROCESS (WIP)
FOR NAVY FIELD CONTRACTING ORGANIZATIONS:
A DECISION RULE

by

John F. Qua

December 1990

Thesis Advisor: David V. Lamm

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This thesis addresses growing concerns about work-in-process (WIP), or backlogs, of small purchase actions at Navy field contracting organizations. Managers of these organizations need an analytical tool to predict if the average age and numbers of contract actions in WIP are increasing. This tool can help management determine if action is necessary to maintain customer service. This thesis develops a two step decision rule to help managers predict whether WIP is getting larger and older, indicating a need for management action.

Management tools and models are reviewed for applicability to the WIP problem. Regression analysis, inventory models, and queueing theory are examined as possible tools for forecasting levels of WIP.

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Optimum Levels of Work in Process (WIP) for Navy Field Contracting Organizations: A Decision Rule

by

John F. Qua
Lieutenant, United States Navy
B.A., University of New Hampshire, 1977

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NAVAL POSTGRADUATE SCHOOL
December 1990

Author: [redacted]
John F. Qua

Approved By: [redacted]
David V. Lamm, Thesis Advisor

[redacted]
William J. Caldwell, Second Reader

[redacted]
David R. Whipple, Chairman,
Department of Administrative Sciences

ABSTRACT

This thesis addresses growing concerns about work-in-process (WIP), or backlogs, of small purchase actions at Navy field contracting organizations. Managers of these organizations need an analytical tool to predict if the average age and numbers of contract actions in WIP are increasing. This tool can help management determine if action is necessary to maintain customer service. This thesis develops a two step decision rule to help managers predict whether WIP is getting larger and older, indicating a need for management action.

Management tools and models are reviewed for applicability to the WIP problem. Regression analysis, inventory models, and queueing theory are examined as possible tools for forecasting levels of WIP.

After concluding that these tools are not applicable, a two step decision rule is designed to predict: (1) the number of purchase requests in WIP and (2) whether the average age of the requests is increasing.

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CHAPTER I: INTRODUCTION

A. INTRODUCTION

Levels of work-in-process (WIP), or backlogs, are a growing concern for Navy field contracting organizations in today's environment. Decreasing budgets and hiring freezes are removing the contracting organization's ability to surge the work force to combat an expanding WIP. Receipts, or inputs, appear to continually increase and organization productivity varies. The result is the average age and the numbers of contract actions continue to build until the organization must take extraordinary measures to preclude serious degradation in customer service.

Navy field contracting organizations need a means to predict when the WIP is becoming too large and too old before these extraordinary measures are necessary. Such a predictor, or decision rule, will assist the contracting organizations in identifying WIP problems that require management attention. Early management attention will prevent WIP from overwhelming the organization's ability to carry out it's mission. The organization will be more efficient and the customer will receive the required goods and services in a timely manner.

This thesis will develop one such decision rule for management. The decision rule will define a relationship between key factors that produce an optimum WIP level for the contracting organization. Month by month, the rule should

tell management that the factors indicate action is needed because WIP is becoming larger and older; or that WIP will be within an acceptable range. Defining these key factors is one goal of this research. Procurement Administrative Lead Time (PALT), the average age of the WIP, the size of the WIP, and the amount of inputs (receipts) and outputs (productivity) are believed to be some of these key factors.

The decision rule will combine these factors and provide a simple indicator for management. The rule will provide a basic indication that WIP is going to grow and age, or remain at an acceptable level. Management will quickly know if action is required.

The decision rule will give managers another means to measure the health and efficiency of the field contracting organizations. A deceptive factor in the WIP problem is PALT. Some organizations have maintained PALT within acceptable standards, while WIP becomes unmanageable. A growing number of customers will wait in excess of sixty days for contracting action to be initiated while the contracting organization's PALT is maintained at twenty days. "Easy" contract actions completed quickly or Issue Group I actions can skew the real picture of the effectiveness of the contracting organization.

B. OBJECTIVE AND RESEARCH QUESTIONS

This research focuses on the various levels of work-in-process (WIP), or backlog, experienced at Navy field contracting organizations. The objective of this research is

to predict when levels of WIP are not optimal for a Navy field contracting organization, through a mathematical decision rule. The decision rule uses key parameters identified in the research. The Navy field contracting organizations can use the decision rule to determine if management actions are necessary to ensure customer service is not degraded by the WIP.

Research Questions:

1. **Primary Research Question**

What are the essential characteristics of an optimum level of small purchase Work-in-Process (WIP) and how can these characteristics be used to predict when Navy field contracting organization WIP management action is necessary?

2. **Secondary Research Questions**

1. How is small purchase WIP measured at Navy field contracting organizations?
2. What are the individual key parameters and how do they affect WIP?
3. When is the size of WIP too large?
4. When is the average age of the contract actions in the WIP too old?
5. How do the dynamics of WIP interact with the dynamics of Procurement Administrative Lead Time (PALT)?
6. What are the effects of a level of WIP that is not optimal on the Navy field contracting organization and it's customers?

C. SCOPE OF THE THESIS

This thesis focuses on Navy field contracting organizations. These organizations include Naval Supply Centers

(NSCs), Naval Regional Contracting Centers (NRCCs), and Inventory Control Points (ICPs). These organizations conduct a high volume of small purchase (less than $25,000) contract actions.

Small purchase data were collected from these organizations and provide the input for development of the decision rule. The focus is on small purchase actions because such actions make up the vast majority of WIP. Large purchase actions and pierside purchase actions were not included in the study because the numbers of these actions are relatively insignificant at Navy field contracting organizations. For example, in one month, a representative NSC received 10,626 small purchase actions, 80 large purchase actions, and 101 pierside purchase actions.

D. RESEARCH METHODOLOGY

A literature review was conducted to examine WIP, or backlog, decision rule methodologies in commercial applications as well as in other military applications. Then, these existing methodologies were reviewed for applicability to the Navy field contracting organization WIP problem.

Data from the Navy field contracting organizations were analyzed to identify significant factors and how these factors interrelate. Operational analysis techniques were then used to develop a decision rule that determines when WIP is growing and aging. The collected data included monthly statistics on

receipts, productivity rates, completions, PALT, and WIP size and average age.

E. ORGANIZATION OF THE THESIS

The remainder of the thesis is organized as follows. In Chapter II, existing models that address WIP, backlogs, and backorders are discussed. In Chapter III, analysis of the sample data and factors that effect the data, as well as relationships among the parameters are presented. In Chapter IV, a proposed decision rule that indicates for managers whether or not WIP is growing and aging is developed. Conclusions and recommendations are presented in Chapter V. Appendix A presents regression models discussed in Chapter III.

F. SUMMARY

This chapter has described the growing concerns about WIP and the need to predict WIP with a management tool at Navy field contracting organizations. The basic framework of the thesis is presented, as well. This thesis will develop a decision rule to predict when WIP is growing and aging.

The next chapter examines existing management tools that address backlogs or backorders, for possible application in developing a decision rule to predict WIP.

CHAPTER II: EXISTING MODELS ADDRESSING WORK-IN-PROCESS

A. INTRODUCTION

Webster's Third New International Dictionary defines "backlog" as "an increasing accumulation of tasks unperformed or materials not processed" [Ref. 20:p. 159]. The identification and management of these accumulations has been addressed in several functional applications. Backlogs, backorders, and work-in-process (WIP) are terms that all address these accumulations.

One fundamental assumption concerning these accumulations is that the person or organization (customers) requiring the task or material will wait for that task to be performed or material to be processed. The backlog/backorder/WIP problem for management then becomes one of maintaining an optimally sized backlog that keeps customer wait time within reason, and minimizes cost while maximizing efficiency. Management must address these problems because customers will not wait forever. In the private sector, profits can be lost and ultimately the health of the firm can be effected. In military applications, large backlogs/backorders/WIP mean efficiency decreases, constrained budgets are further pressured, and readiness suffers.

This WIP problem takes different shapes and is dealt with in different ways. Inventories are frequently maintained using inventory models that plan for an optimal level of

backorders. Management measures construction and maintenance work order backlogs through the use of various formulas and factors. Managers have utilized queueing theory in job process applications to help optimize the WIP problem. This chapter will briefly describe some of these management tools that address WIP. The intent is to provide examples of how backlogs/backorders/WIP are addressed in other functional areas.

B. INVENTORY MODELS

A fundamental inventory model is the economic order quantity (EOQ) model that allows and plans for shortages. It is assumed that the customer will wait to have his order filled under this model. Typically, this model is applicable when the unit value of the inventory item is high. As the unit value increases, inventory holding costs also go up, making backorders a more attractive management option. New car dealerships are prime examples of businesses that can make use of this EOQ model. The dealership may not have the color you desire nor the options you want on a particular model in stock. However, the dealer can certainly order the car the customer wants if that customer is willing to wait a few weeks. The model is not applicable if a shortage causes the customer to withdraw his order (the customer will not wait). The basic model also assumes a constant demand rate for the good and the ordered goods arrive in inventory all at one time. [Ref. 1:p. 457]

This EOQ model with planned backorders derives the order quantity (Q*) and the planned backorder quantity (S*) from a total cost expression of the model. These minimum cost formulas are [Ref. 1:p. 460]:

$$Q^* = \sqrt{\frac{2DC_o}{C_h}\left(\frac{C_h + C_b}{C_b}\right)} \qquad S^* = Q^*\left(\frac{C_h}{C_h + C_b}\right)$$

where: C_h = cost to maintain one unit of inventory for one year

C_o = cost per order

C_b = cost to maintain one unit on backorder for one year

D = annual demand

The resulting order quantities and planned backorder quantities can reveal a savings over a no shortages EOQ model that is attractive to management. Inventory holding costs and ordering costs will be less as fewer orders are generated and less inventory is held in stock. These decreases should offset the backorder costs. If backorder costs increased greatly and the shortages led to lost sales, then this model would not be effective. [Ref. 1]

The Department of Defense (DOD) uses a variation of the EOQ concept with a planned backorders model that is similar. DOD does not plan backorders for its inventories of spares and repair parts, as the implications for readiness are great. Rather, the policy is to try to minimize any shortages by use of implied shortage costs in the calculation of total variable

costs. DOD then uses an EOQ model that attempts to minimize total variable costs, similar to the previous model.

While the model attempts to minimize backorders, it is subject to readiness requirements and funding levels. The implied shortage cost element of the model is used to reflect these constraints. Shortage costs are difficult to determine accurately. In practice, a shortage parameter that reflects readiness requirements or funding realities is used rather than an actual implied shortage cost [Ref. 2:p. E-1]. The result is that when limited funding constrains inventory purchases, low shortage costs are applied to the model. When readiness requirements for a particular weapon system rely on high stockage levels of spares and repair parts, the shortage costs will be high in the model. Brown and others have argued that this use of shortage costs should not be included in the model because shortage costs can not be known in a military environment and that it contributes to excessive stockage levels. [Ref. 2:p. E-2]

There are other factors that blur a true EOQ calculation in DOD. The quantity actually ordered can not be less than three months requirements of material nor greater than three years [Ref. 2:p. 1-1]. The EOQ can be adjusted for other reasons as well. DOD sets safety stockage levels. Managers must specifically consider deferring small quantity requirements to achieve cost savings by waiting for an economic production quantity to order. The cost savings has

to be considered in the context of a negative impact on mission readiness of the effected weapon system [Ref. 4]. Constrained resources drives DOD's approach to inventory management.

C. SHOP MAINTENANCE APPLICATIONS

Expected backorders of repairable units are estimated in military and industry stockage models. In these cases, backorders of the repairable units at the maintenance shop are to be minimized. Readiness suffers when the units accumulate, awaiting repair action.

These stockage models are variations of the Multi-Echelon Technique for Recoverable Item Control (METRIC) model. This model predicts the numbers of expected backorders for the repairable units resulting from maintenance actions. The amount of backorders predicted are dependent on failure rate probabilities, as well as failure detection techniques at the shop, repair cannibalization policies, and stock levels [Ref. 16:p. 10].

A potential failure of this model that can overstate backorders is the model's assumption that the failure of an assembly is the result of only one bad lower indenture item [Ref. 16:p. v]. Spares budgets can be misstated if estimated backorders are larger than actual spare requirements. The result is an inefficient use of scarce funding.

At the local level, the Army calculates actual shop maintenance action backlogs with a straightforward formula.

The Army's formula uses four factors to calculate a maintenance facility's backlog in terms of days of work. The four factors are workload, available man-hours per day, the utilization rate, and the efficiency rate [Ref. 13:p. 14].

Workload is a measure of work accepted at the shop in terms of standard man-hours. Available man-hours per day include direct and indirect shop labor. The utilization factor shows the percentage of available man-hours that is direct labor. The efficiency rate compares actual labor hours used to perform a task to Army standards for that task. This rate is a ratio of the standard hours divided by the actuals for the task. The formula is then [Ref. 13:p. 15]:

$$B = \frac{W}{A * U * E}$$

where B = backlog

W = workload in man-hours

A = available man-hours per day

U = utilization rate

E = efficiency rate

Measuring the backlog can lead to more effective control. An understanding of the factors in the computation can help control and reduce the maintenance backlog. However, this local management tool is limited. The tool is useful to determine the size of the backlog at a point in time, but does not provide a useful forecast of size for planning and budgeting.

D. BACKLOG OF MAINTENANCE AND REPAIR (BMAR)

DOD is also involved in monitoring and managing backlogs in the maintenance of real property. Backlog of maintenance and repair (BMAR) on DOD real property presents a very large problem. These backlogs compete for budget dollars in this fiscally constrained budget environment. During the period 1981-1985, DOD succeeded in reducing the backlog by $.6 billion. However, the BMAR remained at $3.1 billion at the end of 1985 [Ref. 12:p. 20]. This sizeable problem draws much Congressional concern over the deterioration of DOD's real property.

Generally, BMAR is maintenance and repair work, in an installation or base work plan, that has not been accomplished by the end of the fiscal year [Ref. 12:p. 4]. There is no one central DOD definition of BMAR. Each Service uses a slightly different definition.

DOD has tried to control the levels of BMAR. BMAR is a difficult backlog to control because (1) it competes with mission area programs (for funds), (2) of the reduced level of budgets in general, (3) of inflation, and (4) of the increasing requirements of aged prior deficiencies [Ref. 12:p. 17].

Each Service attempts to measure BMAR in a slightly different way. These BMAR models are used to predict future backlogs for budgeting purposes. The Marine Corps uses a non-linear regression model to project BMAR. The Air Force uses

a model on LOTUS 1-2-3 spreadsheet for prediction, while the Army uses a rollover model. All the Services rely on the computer for calculations. [Ref. 12]

The focus of BMAR management also varies among the Services. The Navy's goal is to reduce the backlog to zero, while the Marine Corps wants to keep the BMAR from growing (containment). The Army's goal is to maintain BMAR at a manageable level [Ref. 12:p. 59].

E. JOB PROCESS APPLICATIONS

The WIP problem has also been addressed in job process and service applications. This type of WIP management is somewhat different. Rather than EOQ or regression models, job process applications normally rely on queueing theory. Queueing theory helps managers deal with waiting lines. Waiting lines are costly in terms of losing disgruntled customers, or being inefficient. Queueing theory helps managers make informed tradeoffs between added costs and better service or an improved process. If cost was not a factor, no customer would have to wait for service or no job process would back up. Queueing theory can be used to determine the average number of units waiting in the system (the backlog) and average wait time, among other things.

Many variations of queueing theory models exist. The models are based on assumptions about how many channels are available (how many servers or lines); what the arrival probability distribution of the units is; what the service or

repair time probability distribution is; and what the actual queue discipline is (e.g., first come, first serve). [Ref. 1]

Job shop scheduling can be addressed with queueing theory. The type of process and service facility, such as a repair action in a maintenance shop, can be described as a queueing system. When the arrival rate of units for repair is greater than the repair rate, a waiting line develops. Queueing theory can be used to examine system characteristics and effectiveness. Then things like different queue disciplines (or priority rules) and changing the number of servers can be tested to define the most cost efficient system.

Testing various priority rules can be a viable solution to job shop scheduling problems. However, the approach has been criticized because of the complexity of calculations needed to describe a complex job shop queueing system [Ref. 17:p. 18]. Computer simulation can be used to deal with this complexity.

F. BACKLOG OF WORK MODEL

A backlog of work model has been developed in connection with the construction industry. For this model, backlog is defined as all uncompleted work on hand, both bonded and unbonded. Rhye has applied this model to the mechanics of the construction firm [Ref. 14]. He uses the model to determine a firm's optimal level of capitalization, an optimum mix of operating and working capital, and a firm's bonding capacity

[Ref. 14:p. 13]. This is an industry specific model because of the unique nature of the construction industry.

G. SUMMARY

This chapter has reviewed several management tools that address backlogs/backorders and WIP to explore possible existing solutions to the WIP problem at Navy field contracting organizations. Specifically, inventory models, queueing theory models, and regression models were briefly discussed.

The following chapter describes the research data collected and attempts to use these models and the data to predict the amount of WIP at a Navy field contracting activity.

CHAPTER III: DATA ANALYSIS

A. INTRODUCTION

The Naval Supply Systems Command provided data from seven Naval Supply Centers (Charleston, San Diego, Puget Sound, Oakland, Norfolk, Pearl Harbor, Jacksonville); five Naval Regional Contracting Centers (Pensacola, San Diego, Philadelphia, Washington, Naples); and two Inventory Control Points (Aviation Supply Office, Ships Parts Control Center).

There are some wide variations and fluctuations in certain data. The variations can be explained, at least partially, by some factors which are addressed in this chapter.

The WIP problem is discussed in the context of various models examined in Chapter II. The intent was to determine if one of these existing models can be used to predict WIP at a Navy field contracting activity. Regression, queueing, and inventory models were applied in this chapter. However, before addressing the models, a detailed look at the data is presented.

B. THE WORK-IN-PROCESS DATA

The data collected are summarized by month for each activity, by fiscal year. The period of observation is fiscal years 1988, 1989, and through February, 1990. The following data are provided for each activity: the beginning WIP, monthly receipts, monthly cancellations, monthly awards,

monthly completions, man hours per month, monthly productivity, monthly Procurement Administrative Lead Time (PALT), and the crew days of the WIP.

The beginning WIP is the number of purchase requests at the field contracting activity that have not yet been completed (either awarded or cancelled) at the beginning of the month.

The monthly receipts are the number of purchase requests that actually arrive at the contracting activity that month. They represent requests, from the activitys' customers, to buy materials or services.

Monthly cancellations are the number of purchase request documents that are actually cancelled during the month. These cancellations can be initiated by the customers, as well as the buyers.

The monthly awards are the number of purchase requests that are placed on order during the month. This is the number of requests that are ordered with vendors during the month.

Monthly completions are the total number of purchase request documents that have been finished by the buyers during the month. Monthly completions equals monthly awards plus monthly cancellations.

Man hours per month are the number of hours actually worked during the month, by the buyers of the activity.

The productivity rate for the month is a measure of how many completions the activity turns out, per man hour. It is

calculated by dividing monthly completions by man hours per month.

PALT is an average measure of the number of days it takes to place a purchase request on order. PALT is generally measured from the time the purchase request reaches the buyers desk until the request is placed on order.

Crew days of WIP represents the number of days of output for the activity required to reduce the size of the WIP to zero. In other words, the size of the WIP represents "x" days of output of the activity. Crew days are based on the last twelve months of average daily output.

These data are used to calculate, after the completion of the month, the next month's beginning WIP. It is a mechanical calculation, much like the Army shop maintenance calculation, and is not a predictor. WIP for the next month equals the beginning WIP for the month just completed, plus that month's receipts, minus that month's completions (cancellations plus awards):

WIP = BEG WIP + RECEIPTS - COMPLETIONS

For example, the October, 1989 beginning WIP for one NSC was 3,710. During that month the activity received 11,994 purchase requests and completed action on 8,132 documents. Therefore, the November, 1989, beginning WIP is:

7,572 = 3,710 + 11,994 - 8,132

C. FACTORS AFFECTING THE DATA

There is tremendous variation throughout the twenty-nine months of collected data. Monthly receipts is one such data category that fluctuates. For example, one NSC received 9,412 purchase requests in January, 1989, and more than twice that number (21,503) in June of the same year. In October, 1989, an ICP received 1,727 purchase requests while three months later, in January 1990, this ICP took in 7,092 documents. The fluctuations appear at the NRCCs as well. For example, one NRCC received 4,047 purchase requests in March, 1988, and about half that number, 2,078, in July of the same year.

Several factors affect the number of receipts a field contracting organization takes in each month. Purchase requests must be funded by the customer. Receipts of purchase requests can fluctuate with funding. Generally, the expectation is that more purchase requests will be received at the start of the fiscal year, in October. Also, some Operating Target (OPTAR) Holders are issued monies quarterly so there could be an increase in receipts in January, April, and July.

Receipts will tend to fluctuate with the tempo of operations of the customer, as well. Field contracting organizations supporting units that are preparing for an upcoming deployment (Desert Shield, for instance) will tend to receive more purchase requests during these preparation periods. There is an expectation that acts of God such as

hurricanes and earthquakes will tend to increase the receipts at the field contracting activity.

Awards and cancellations also fluctuate widely during the observed period. One NSC cancelled a low of 547 documents one month, to a high of 2,811 documents another. The same NSC awarded a low of 7,376 purchase requests one month, and had a high award month of 13,749 during the observed period. The ICPs and NRCCs displayed the same fluctuations. An ICP awarded a low of 2,229 documents during a month; and a high of 6,356. The same ICP cancelled a low of 347 documents during one month and a maximum of 1,682 another month. One NRCC cancelled 0 documents in October, 1987, and cancelled 668 documents in December, 1989. The same NRCC awarded a low of 310 purchase requests one month versus a high of 3,694 another month.

Budget pressures may effect the numbers of cancellations each month. Inventory managers can cancel or modify (partially cancel) their purchase requests in response to the specific supply position of their managed items. However, managers may cancel or modify because there may be a shortfall of funding. There simply may not be enough money to procure all items required. In these cases, inventory managers use judgement as to which items to keep on order, and which to cancel. It is expected therefore, that as budgets shrink cancellations would increase.

There is an element of human nature that must be considered as well. In an environment of increased pressure and growing workloads, it is expected that cancellations will increase. This is expected because cancellations are a relatively simple way to attack a growing WIP. Some purchase requests are cancelled because preparation procedures are not followed exactly by the customer. In a less intense environment, a purchase request that is missing information, or is filled out incorrectly, can be resolved by a telephone call from the buyer to the customer.

The number of awards probably fluctuate over time with the quality of the workforce at the organization. Workforce disruptions, such as losing experienced buyers and hiring new, inexperienced personnel can slow the numbers of awards.

Awards, like receipts, will fluctuate with the tempo of operations. As that tempo increases, there are likely to be more, higher priority purchase requests. Higher priority purchase requests take precedence over lower priority requests at the contracting organizations.

Awards may tend to fluctuate with fiscal year funding, as well. It is expected that fiscal year end awards may be increased in order to obligate monies that will otherwise expire.

Man hours per month vary widely, too. An NSC had a low of 5,943 hours one month versus a high of 13,207 hours another month. An ICP worked a high of 6,726 hours in March, 1988,

but worked its' lowest total (2,025 hours) in May, 1988. One NRCC worked a low of 957 hours one month versus a maximum of 3,955 hours another.

The man hours worked each month can reflect managements' flexibility to respond to increasing workloads. Some of the increases can be attributed to the ability to work overtime. Others may represent temporary hires brought on to work growing WIP. It is expected that a fiscally constrained environment of lowered budgets will tend to flatten these fluctuations in man hours.

Productivity varies greatly at the field contracting organizations. One NRCC had a low monthly productivity rate of .16 versus a high of 1.75. An NSC ranged from a low rate of .89 to a maximum monthly rate of 2.25. The range at one ICP was a minimum productivity rate of .32 and a maximum of 1.93.

The large variations in the productivity rate is partially explained by the large fluctuations in completions (awards and cancellations) and man hours because the rate is calculated by dividing completions by man hours. However, there are other factors. For instance, during the twenty-nine month period of observation, most of the field contracting organizations were installing automated purchasing capabilities. Disruptions caused by the actual installation of machines and software, as well as the required buyer training probably lowered productivity. However, after the

initial training and learning process, it is expected that productivity will rise.

PALT fluctuates widely, also. Several factors contribute to this fluctuation. A general increase in PALT over time can be attributed to increased administrative requirements on the buyers, brought about by laws and regulations. The Competition in Contracting Act is one example of a law that contributed to increased PALT. Another example is the 1987 DOD Authorization Act, which required reductions in unpriced orders. As a result, PALT figures increased through 1988. Officials at an ICP stated that awards completed quickly through unpriced actions had offset PALT effects of awards that take a longer time [Ref. 19:p. 32].

At the individual contracting activities, PALT is complicated by several other factors. Issue Group I purchase requests must be worked quickly. These priority requests "go to the head of the line". Some procurement actions can be completed easily and quickly. Blanket Purchase Agreement (BPA) calls are one type of "easier" action for the buyer. Unpriced orders, as discussed above, require less time to complete. However, these type of orders are much more strictly controlled now. Usually, individual buyers must seek higher authority approval for an unpriced order.

The foregoing describes procurement actions that serve to keep PALT figures low. There are other procurements that serve to increase PALT. Problem, or hard to buy items can

lengthen PALT. Purchase requests that require more administrative effort on the part of the buyer to conduct research, solicit quotes, or better define requirements with the customer will lead to longer lead times.

The paradox of PALT, however, is that many Navy field contracting organizations have maintained PALT within established and acceptable ranges, while growing levels of work-in-process become older. An organization can maintain PALT at a goal of twenty days while a percentage of the WIP ages well beyond the twenty day period. This fact frustrates those customers who are not receiving service within the advertised PALT timeframe.

A month by month summary comparison of these key data revealed no uniform patterns. The mean number of receipts were sometimes greater in October, as expected, and sometimes not. Awards, cancellations, productivity, and man hours per month all are expected to fluctuate with receipts; however, no clear pattern was discerned. During some months awards increased with receipts, as expected; and other months awards decreased when receipts increased. There was generally an increase in awards and cancellations at the fiscal year end (September/August). Increases in PALT tend to lag a month to several months behind large increases in receipts. In fact, some months with larger than usual receipts show good PALT numbers. The PALT problem typically shows up later.

D. REGRESSION ANALYSIS

Several regression models were developed in an attempt to predict WIP, using the MINITAB software package. The first step in developing these models was to identify independent variables that could be used to predict the level of WIP. The independent variables considered were the monthly figures for receipts, cancellations, awards, completions, productivity, PALT, man hours, and crew days.

The independent variables were plotted individually against the dependent variable, WIP, to examine the relationship between variables. The resultant scatter plots showed a wide variety of results. Some plots showed little, if any, apparent relationship between the variables. Some relationships appeared to be linear. The variable relationships differed between activities as well.

At one NRCC, there was a linear relationship between WIP and receipts, awards, completions, and crew days. The only apparent linear relationship between dependent and independent variables for an ICP was with completions and crew days. Plots for an NSC showed that receipts, completions, and man hours appeared to have a linear relationship with WIP. Patterns for each activity were less discernable for other independent variables.

Correlation matrices were run to further examine the relationships between variables. The correlations again pointed out the differences between activities. For one NRCC,

there were no negative correlations with WIP. Another NRCC showed negative correlations between PALT and WIP, and cancellations and WIP. A negative correlation is expected between cancellations and WIP. It makes intuitive sense that as cancellations increase, WIP will decrease. Conversely, it is not intuitive that as PALT increases, WIP decreases. Rather it would seem that WIP should increase as well in this case.

One ICP showed all positive correlations between the independent variables and WIP as well. Yet another NSC, as well as some other activities, showed a negative correlation between receipts and WIP. This suggests that as receipts increase, WIP decreases. Again, this is not an intuitive relationship.

Regression models were developed for the NRCCs, NSCs, and ICPs which contained six independent variables believed to be the most significant factors. The models described a linear relationship. The six independent variables selected were: (1) monthly receipts, (2) monthly completions, (3) man hours per month, (4) monthly productivity, (5) PALT, and (6) crew days. In general, these models produced a relatively high coefficient of determination (r squared) value, and a low estimated standard deviation (s) around the regression line.

In validating these models, several problems were encountered. The most severe problem was that, for most models, the error terms appeared to be correlated. This

problem violates an assumption of least squares linear regression; namely that the error terms are uncorrelated. A method such as the Prais - Winsten or Cochrane - Orcutt must be used to correct the model for the correlation of error terms [Ref. 11:p. 799]. These methods transform the dependent variable to correct the problem.

Alternate linear regression models were developed for the activities that relied on fewer independent variables. Each activity used different variables, depending on correlations between variables. These models generally produced higher estimated standard deviation values and lower coefficients of determination. The models also violated some assumptions for least squares linear regression.

Examples of these regression models are presented in Appendix A. Two models are presented for a representative NRCC, NSC, and ICP. The assumptions for the regression model are tested in each case.

The violation of regression model assumptions must be corrected before the models can be considered valid. Further model development and testing is required to determine if regression analysis is a viable means of accurately predicting WIP. There is however, no one model for all activities. Each organization requires it's own unique regression model based on it's own data.

E. INVENTORY MODELS

While it is possible to fit the WIP problem into the context of an inventory model, this approach is not helpful in understanding the problem. In order to be of value, costs have to be introduced into the model to get a cost effectiveness measure. Some of these costs have to be estimated. The wide variety of items procured and the varying importance of different items (mission essentiality) will make an implied shortage cost estimate extremely rough indeed.

Inventory models derive a minimized backorder quantity and an optimal order quantity that is cost effective. It does not seem realistic to suggest an optimal order quantity (number of completions per month) in the WIP problem. The number of purchase orders completed per month is a function of more than demand and various costs. Priorities, administrative requirements, budget pressures, and productivity, among other factors, weigh heavily on the "order quantity" as well. Clearly, an adaptation of an inventory model would not provide any realistic description of an optimum WIP.

F. QUEUEING THEORY

Queueing theory, as applied in job processes and job shop scheduling is not particularly useful for the Navy field contracting organization WIP problem. The contracting organization could be styled as a queueing system, in order to try to determine the average number of units (purchase requests) waiting in the system and the average wait time.

However, assumptions of existing mathematical models can only be approximated, at best.

The arrival distribution of purchase requests (monthly receipts at the activity) is not Poisson. Each arrival is not always independent of others; and it can be predicted that some months will exhibit a higher arrival rate. The arrivals do not necessarily follow a random pattern.

One queueing theory model assumes the distribution of the service times is exponential (the amount of time a buyer takes to place a purchase request on order). The number of factors that effect this service time at the contracting activity prevent this assumption from being met. The priority system for purchase requests; differing procurement methods that effect the speed at which a purchase request is placed on order (BPAs); the amount of procurement automation in the office; and fiscal year funding constraints, among other factors, prevent the service time distribution from being exponential.

First come, first serve is one priority rule, or queue discipline, in queueing theory. This rule is not applicable at the contracting activities. The activities operate under a priority system, with the highest priorities being worked first. Also, high priority purchase requests can arrive in the form of "walk throughs", necessitating immediate action.

The servers (the buyers) are not identical, either. Experience, familiarity with automated purchasing systems, and

workload contribute to make each buyer's productivity different. The contracting activities may be organized such that all buyers are not created equal. For example, some activities can be organized by commodity, with some commodities being easier to purchase than others (circuit boards versus toilet paper).

There are other mathematical models for queueing theory that do not rely on the assumptions addressed here. Many queueing systems are so complex that the mathematics of the model are extremely difficult. It can not be determined if the models apply or not, on many occasions. However, computer simulation could be used to approximate the arrival and service distributions, as well as the queue discipline, in developing a queueing model. The complexity of calculations, along with the assumptions that do not apply, make queueing theory an unsuitable tool to predict WIP at Navy field contracting organizations.

G. INTERVAL ESTIMATES

Interval estimates were developed in an attempt to define reasonable expectations for inputs and outputs to WIP size. These estimates are intervals that will contain, with some level of confidence (i.e., 95 percent confidence), the real mean for the input or output. The t distribution and the t statistic are used to calculate these interval estimates because the sample size is at least twenty-five so the random variable (input or output) approximates a normal distribution

per the central limit theorem; and the population variance is unknown.

These estimates were developed to determine the limits of reasonable inputs and outputs for a decision rule in the next chapter. For instance, one ICP's mean number of receipts during the observed period is 2,197. It can be stated with 95 percent confidence that the population mean of monthly receipts will fall between 1,888 and 2,505 receipts. A 90 percent confidence interval for the same ICP is 1,940 to 2,453 receipts. These intervals are very wide and therefore provide little definition for a decision rule. The estimates are based on the twenty-nine months of collected data. Other intervals were derived for cancellations, awards, completions, man hours, productivity, and PALT. Actual intervals were calculated for two NSCs, two ICPs, and two NRCCs. These intervals will vary from activity to activity.

H. SUMMARY

This chapter described the WIP data that were collected. Analysis was performed revealing tremendous variability. Possible reasons were discussed for that observed, wide variability in the data. Multiple regression models were developed to predict WIP, but indications were these models were not valid. Further model refinement based on more years of data is required before it can be determined if regression can be used to accurately predict WIP levels. Inventory models and queueing theory did not prove useful in predicting

levels of WIP. Statistical confidence interval estimates were computed for the means of the inputs and outputs. These estimates were not considered helpful for developing a decision rule because of the large intervals that resulted.

Having attempted to use these existing tools and models to predict levels of WIP unsuccessfully, the next chapter will develop estimates of inputs and outputs based on other methods. Then these estimates will be used to develop a decision rule for predicting whether or not WIP is growing or aging at Navy field contracting organizations.

CHAPTER IV: A PROPOSED DECISION RULE

A. INTRODUCTION

In trying to develop a useful decision rule, an optimal WIP must be analyzed first. It seems reasonable to focus on the mix of the documents that make up the WIP, as well as the age of the WIP. Estimates of inputs and outputs to the WIP were addressed next as essential elements of the decision rule. Forecast tools were developed to help the small purchase organization manager estimate these factors. Then the forecasts of inputs and outputs were used together in a two step decision rule to determine if WIP will grow and age beyond an optimum level in the coming month.

B. COMPOSITION OF AN OPTIMAL WORK-IN-PROCESS

The actual make up of purchase requests in the WIP is an important consideration in trying to determine whether the WIP is too large or too small. Naturally, each individual Navy field contracting organization's WIP will have unique characteristics. Generally the mix of purchase requests is expected to follow a standard composition based on the frequency of requests per priority level. For example, high priority purchase requests are usually reserved for urgent requirements or deployed operational unit support. A standard mix of documents in the WIP would contain a smaller percentage of these documents. Lower priority purchase requests,

representing routine, recurring requirements is expected to make up the majority of the small purchase WIP.

However, the make up of the WIP does not necessarily follow these guidelines. Many of the high priority purchase requests will arrive in the form of bearer walk throughs. These types of requests receive immediate attention, and therefore do not really enter the queue. There are some high priority purchase requests in the WIP, but not as many as is expected. Special operations (e.g., Desert Shield) or Acts of God can skew the picture of the WIP as well. These conditions can change the make up of the WIP, providing more high priority requests, or just more requests, into the system.

Each activity has a PALT goal established. This goal ranges from 10 - 25 days for NRCCs and NSCs to 100 - 132 days for ICPs. The differences in the goals reflect differing customers, items procured, and conditions.

An optimal WIP will not have an average age of the purchase requests older than the PALT goal of the activity. Therefore, in a perfect, homogeneous world, an activity with a 20 day PALT goal should be able to complete enough requests per day to maintain the average age at, or near, 20 days. In theory, if the activity can complete 450 purchase requests per calendar day, the activity will maintain an optimal WIP as long as it does not take in more than 13,500 requests during the month (worst case). This number of receipts would leave

(assuming 0 WIP to start) no more than 4500 purchase requests in WIP, less than 20 days old. If the number of receipts exceeds 13,500, and there is no increase in the number of completions per day, the activity approaches a trouble level of WIP.

The goal of the optimum WIP is to minimize the average age and number of the purchase requests in the WIP. The world is not homogeneous. Different activities have different mixes of requests, and PALT may be too low when dealing with an aged WIP. Therefore, managers must set bounds around their WIP, versus focusing on perfect world numbers. The boundaries should reflect each individual activity's situation. The average age of the WIP may be somewhat higher than PALT at some activities. Managers must weigh customer service, the mix of documents and the environment in deciding how much above PALT the age of the WIP can grow.

The essential question facing the manager is whether or not the WIP is going to get larger next month, or smaller. The decision to be made is whether or not, as a result of the change in the size of the WIP, management action is necessary. The answer to the initial question should be based on a reasonable expectation of inputs at the activity as compared to an estimate of outputs. The result of this comparison should indicate whether the WIP is expected to grow beyond a size that keeps the age of the WIP close to the PALT goal.

C. ESTIMATES OF INPUT

The essence of the WIP problem is basic. WIP is created, and grows, when inputs to the system are greater than outputs from the system. Simply, this means more purchase requests are received than can be processed during a given month. A reasonable forecast of purchase request receipts is an essential factor in any decision rule concerning the size of WIP at an activity.

As discussed in the previous chapter, interval estimates can be developed to predict the monthly mean for inputs and outputs. This method can be applied to monthly receipts. A prediction of receipts can be based on the mean and interval estimate derived from the twenty-nine months of historical data. Either the sample mean, or the higher end point of the confidence interval can be used as the predictor. Using the higher end point of the confidence interval would be the more conservative approach.

This method is probably not the best forecasting tool. By relying on two year old data, the method ignores year to year trends. For instance, the fiscal year (FY) 1988 mean for monthly receipts was 2,703 at one ICP. In FY 1989 the mean monthly receipts was 1,926 at the same ICP. FY 1990 data show the mean monthly receipts to be 1,627. Clearly there is a trend of less receipts per month at this ICP, from FY 1988 through FY 1990. The use of a twenty-nine month mean and

confidence interval based on historical data will be biased towards forecasting more receipts, because of FY 1988.

There are two other methods that could be used to provide a forecast of monthly receipts for use in a decision rule. The first is to rely on just the prior year's mean monthly receipts as a predictor. A second method is to use a three month moving average to predict monthly receipts.

A comparison of these two alternatives was run to select the most accurate forecasting tool. Six activities were tested, using both the prior year mean monthly receipts and three month moving averages as forecasting tools, for each month in FY 1989 and FY 1990 (through February). The results of these tests were inconclusive. For the five month period forecasted in FY 1990, the FY 1989 mean of monthly receipts proved to be a more accurate predictor than a three month moving average. In five out of six activities, the FY 1989 mean monthly receipts was the more accurate forecasting tool.

However, in forecasting monthly receipts for FY 1989 for the same six activities, a three month moving average was a better forecasting tool than the mean of FY 1988 monthly receipts. The moving average was a better predictor in four of the six activities tested. Interestingly, the one activity that showed the moving average to be more accurate for FY 1990 predictions, showed the prior FY mean monthly receipts to be a more accurate forecasting tool for FY 1989.

These tests reveal no conclusive evidence that one forecasting method is better than the other. However, the researcher recommends the use of the three month moving average as the forecasting tool for monthly receipts. This tool reacts to trends in the data, as opposed to the static 12 month mean, which does not react. Trends in the data during the fiscal year can be better reflected in a three month moving average forecast.

Any forecast of monthly receipts must be tempered with the qualitative judgement of the manager. The three month moving average provides a starting point for the manager. This forecast should be modified with the effects of the particular environment, at the particular time in the fiscal year. For instance, are customers getting ready to deploy on a major mission, such as Desert Shield? Is the estimate sufficient, given that the month forecasted is August, the last full month before purchase requests are cut off for the fiscal year? Managers must consider such factors in any forecast of monthly receipts to make the estimate as accurate as possible.

D. ESTIMATES OF OUTPUT

Outputs from the system must be estimated, to compare with input estimates, to predict if WIP will grow or shrink. Monthly completions are an obvious measure of output from the system. These completions can be forecasted as the measure of output to be applied to a decision rule.

Completions can be estimated in the same way that monthly receipts were estimated: through a three month moving average. However, this estimate for output is not always reasonable. The Navy field contracting activities have little control over the number of purchase requests they receive during a given month. The activities do, however, have some control over the number of purchase actions they complete during the month. Therefore, to base a forecast of output on the previous three months of data for monthly completions ignores this factor of control.

The number of monthly completions is a function of how many man hours are worked that month, and the work force productivity rate for the month. Managers have at least some control over these two factors. Man hours will be higher or lower based on overtime, vacation policies, and manning levels, for instance. The small purchase activity manager effects these policies and therefore is able to provide a more accurate estimate of hours for an upcoming month.

By the same token, productivity can be effected by the manager. A tiger team approach to completing one large section of the WIP, an office remodeling project, or a planned shift in buyer functions all have productivity implications that the manager should consider.

Therefore, the estimates of output for a decision rule should be based on man hours per month and monthly productivity. The estimate of man hours can be derived from a

moving average or a historical mean. However, this approach ignores the manager's control over man hours. Some percentage of man hours can not be controlled, such as the hours lost to illness. Some managers may have historical data with which to offset an estimate of future monthly hours for sick days.

A manager can estimate the number of man hours for an upcoming month more accurately than relying on historical data. Simply, a manager can estimate the man hours by multiplying the hours in a work day (8), by the number of work days in a month (22), by the number of buyers in his purchasing department. The total must then be lowered for known vacation time, and estimates of sick/emergency leave days. For example, in a small purchase department of 50 buyers, the total number of hours to be predicted for an upcoming month are 8 * 22 * 50 = 8,800 hours; less vacation and sick time. Assuming 800 hours for these decreases to the total, the manager is left with an estimate of 8,000 man hours for the coming month.

Productivity is more difficult for the manager to predict with certainty. This factor can be more accurately forecasted using historical data, adjusted for qualitative factors.

While the productivity rate can fluctuate widely from month to month, the fiscal year to year means are very similar for each organization. For example, the FY 1989 productivity rate for an activity was 1.36, while it was 1.40 through February in FY 1990. Another activity had a rate of 1.56 in

FY 1989, and 1.52 rate in FY 1990. A third activity had a 1.22 rate in FY 1989, and 1.29 in FY 1990. The point is that these mean productivity values provide a good basis for the manager to use as a forecasting tool for an upcoming monthly rate.

The estimated rate should be tempered by qualitative factors. An office remodeling project, a planned, short term tiger team approach, or a new training schedule can all effect the monthly productivity rate.

The manager can then get a more accurate estimate of his next month's output, the completions, with these forecasts of man hours and productivity. Simply, the estimated man hours are multiplied by the estimated productivity rate. The result is a forecast for monthly completions.

E. THE DECISION RULE

Armed with a reasonable projection of monthly receipts and a forecast of completions for the upcoming month, the manager can now determine what the implications are for the WIP. This is a two step process. He must predict whether the WIP will increase during the coming month and, if so, whether the increase requires management action.

The first step is relatively straightforward, once the forecasts for inputs and outputs are derived. The projection of monthly receipts is compared to the estimate of completions for the month.

This comparison will predict for the manager whether or not the WIP will grow in the coming month, and by how much. For example, a three month moving average forecast for receipts at one NSC for October, 1989, is 13,506 purchase requests. Productivity for the fiscal year just completed is 1.36, which is a good estimate for illustration. Of course, the manager may adjust this rate based on qualitative factors. Finally, assume the manager estimates his work force man hours for the coming month at 8,000 hours. The assumption presumes that the manager, as discussed above, will provide a more accurate estimate than a reliance on historical data.

The projection of completions for October, 1989, then becomes 10,880 purchase actions (8,000 * 1.36). This estimate when compared to the projection of receipts, predicts an increase in the WIP of 2,626 purchase requests. The forecast shows the inputs will be greater than the outputs.

The next step for the manager is to determine what the increase implies for the activity's WIP. Can this increase be absorbed with little effect on the age of the WIP? Is this increase of sufficient size to warrant concern about the activity's ability to provide timely service to its customers?

There is no straightforward mathematical calculation for the answers to these questions. The dynamics of WIP, of when particular purchase requests are worked, affects the average age of the WIP. The forecasts can predict if the WIP will increase in size. However, this increase in size does not

necessarily bring about an increase in the average age of the WIP.

Managers need an indicator that will show if the age of the WIP is going to grow. One such proposed indicator is whether the new estimate of WIP represents more completions per PALT day than current forecasts of daily completions.

The NSC, in the example presented, had an existing WIP of 7,480 purchase requests. The forecasted increase of 2,626 documents raises the predicted WIP to 10,106 actions. A twenty day PALT goal means this WIP represents 505 completions per PALT day. Management can use the PALT goal or current PALT for this calculation, depending on the specifics of the activity. Daily completions are projected to be 362 (10,880 / 30 days). Daily completions are based on calendar days vice work days because PALT is based on calendar days.

This indicator should tell the manager that his WIP will increase in average age. The projection for the activity is such that the number of completions will not allow a significant erosion of the WIP age, while still maintaining a PALT goal. In fact, the age will grow because of the large difference between the WIP described in PALT days, and the estimate of daily completions.

This indicator was tested on the sample data. Monthly completions and the WIP were treated as estimates; and then a prediction was made, using the indicator, as to the whether the age of the WIP would grow. Twenty-four predictions were

made, for six different activities, over a four month period in fiscal year 1990. The indicator described above accurately predicted the average age would increase, or decrease, seventeen times. In two other cases, the indicator values were very close (but not equal), and the average age stayed the same.

This indicator, coupled with a realistic review of the environment, the time of the fiscal year, and the mix of the existing WIP can indicate to the manager whether action is necessary. Generally, action is necessary when the forecasts show an increase in the size of the WIP, and indications are that the age will grow beyond an ability to provide good customer service. This proposed two step decision rule is summarized as follows. Step one: Compare estimates of inputs and estimates of outputs for the coming month. WIP is expected to grow in numbers of purchase requests if the estimate of inputs is greater than that of the outputs. Step two: Compare the estimated WIP, expressed in terms of daily PALT output, with the estimate of daily outputs. WIP is expected to age if the estimated WIP (per PALT day) is greater than the estimated output (per day). Armed with this information, management can decide whether to take some action to preserve customer service. This proposed two part decision rule is provided as an analytical tool for the small purchase department manager to use. The rule can help the manager decide when action is necessary.

F. SUMMARY

This chapter has discussed an optimum WIP in terms of the mix of purchase requests and the average age of the documents. The optimum WIP is closely related to the PALT goal, in theory. Real world mixes of WIP and other trends in receipts and completions will modify the optimum WIP for each individual field contracting activity.

Estimates of inputs (receipts) and outputs (completions) were then derived for the coming month. The estimates were compared, in the first step of a proposed decision rule. If the input estimates are greater than the output estimates, managers are cautioned that the size of the WIP is predicted to grow.

Secondly, managers must determine what this growth means in terms of customer service. An indicator that the average age of the WIP will grow is determined through comparison of estimated WIP by daily PALT output (WIP / PALT goal) with estimated completions by daily output (completions / 30 days). If the WIP, in terms of PALT output, is estimated to be greater than estimated daily completions, it is predicted that the average age of the WIP will grow. Managers must also apply judgement factors to this indicator to ensure a more accurate estimate of the WIP is derived.

The next chapter will provide conclusions and recommendations regarding WIP at Navy field contracting activities.

CHAPTER V: CONCLUSIONS AND RECOMMENDATIONS

A. INTRODUCTION

This chapter will first provide conclusions drawn from the research of WIP at Navy field contracting organizations. Next, recommendations are provided that address the WIP problem. The primary and secondary research questions are then presented, recapping the answers derived from the research. Finally, recommendations for further research are presented.

B. CONCLUSIONS

1. A mathematical formula, by itself, can not accurately predict future levels of WIP.

As discussed in Chapter III, there are many hard to measure qualitative factors that influence the size of the WIP. Additionally, it was shown in Chapter IV that managers have control over some WIP parameters, such as man hours, enabling them to predict future levels with more accuracy than can be provided by a mathematical decision rule that relies solely on historical data.

2. Linear regression models discussed in this thesis are not accurate predictors of WIP levels.

Chapter III and Appendix A discussed how the models violated assumptions of least squares linear regression. The models presented are not valid because of these violations, and can not be relied upon.

3. Other models that address backlog minimization, such as inventory models and queueing theory models, are not helpful in understanding this particular WIP problem.

The assumptions for basic queueing models can not be met when applying the techniques to the small purchase procedures at Navy field contracting organizations, as described in Chapters II and III. Cost estimates, needed to apply the inventory models, can not be accurately predicted, as shown in Chapter III.

4. The use of historical, arithmetic means must be used with caution when developing forecasts.

Aged data may not accurately predict the future. It was demonstrated in Chapter IV that a moving average technique can better capture trends in data for some WIP parameters than an historical mean based on twenty-nine months of data.

5. Managers of small purchase departments can react to indications that WIP is growing and aging and thereby preclude a decline in customer service.

Managers must use forecast tools and indicators to predict when the level and age of the WIP requires action; and then take action. The two step decision rule described in Chapter IV is a tool managers can use to predict if the WIP will grow and age. This tool gives managers the chance to react.

C. RECOMMENDATIONS

1. Provide the two step decision rule to Navy field contracting organizations so this tool can be tested, and then used to predict when WIP is becoming suboptimal.

The field contracting organizations can track forecasts for a six month trial period and determine the accuracy of the rule at the local activity. The two step decision rule can then be used as one indicator of the need for management action to maintain customer service.

2. Collect and report data on the actual mix of purchase requests in the WIP at each activity.

Stratify these data by priority classification. This information provides more insight into the WIP problem and can further indicate to the manager whether action is needed. These data would help complete a WIP "snapshot".

3. Actively address the WIP at Navy field contracting organizations.

The literature review shows that PALT, not WIP, gets most of the attention in the professional literature. Managers can not be lulled into managing only to PALT. The focus for these small purchase departments must be to strike a balance between maintaining the PALT goal and keeping WIP from growing and aging beyond reason.

D. ANSWERS TO THE RESEARCH QUESTIONS

Primary research question: What are the essential characteristics of an optimum level of work-in-process (WIP) and how can these characteristics be used to predict when Navy field contracting organization WIP management action is necessary?

Answer: The essential characteristics of an optimum level of WIP are a minimized average age, and the number and mix of

purchase requests in the WIP. As discussed in Chapter IV, the WIP is optimum if the average age is at or near the goal for PALT, and the size of the WIP is not growing.

A two step decision rule was developed in Chapter IV to determine if WIP management action is necessary. First, estimates of input and output were compared to determine if WIP is growing. Second, it was determined if the age of the WIP is increasing through comparison of estimated WIP by daily PALT output to estimated completions by daily output. If the rule indicates the WIP is growing and aging, management action is necessary.

Secondary research questions:

1. How is small purchase WIP measured at Navy field contracting organizations?

Answer: WIP equals the beginning WIP for the month just completed, plus that month's receipts, minus that month's completions. WIP = BEG WIP + RECEIPTS - COMPLETIONS.

2. What are the individual key parameters and how do they affect WIP?

Answer: The key parameters are monthly receipts, monthly completions (awards plus cancellations), man hours per month, monthly PALT, and monthly productivity. As discussed in Chapter III, fluctuations in each of these parameters can mean increases or decreases to WIP. Correlation analysis in Chapter III pointed out that these parameters had different

effects on WIP at different activities, and were not always intuitive in those effects.

3. When is the size of WIP too large?

Answer: The size of the WIP is too large when it is greater than a boundary set by management, as discussed in Chapter IV. This boundary can be tied to the number of completions the activity can accomplish per day, compared to the number of completions the WIP represents per PALT day. If the latter figure is greater than the former, the WIP is too large.

4. When is the average age of the contract actions in the WIP too old?

Answer: The average age is too old if it is greater than the PALT goal for the activity, as discussed in Chapter IV. An age at or near the PALT goal maximizes customer service. Managers are cautioned that the PALT goal may be too low when dealing with an over-aged WIP.

5. How do the dynamics of WIP interact with the dynamics of Procurement Administrative Lead Time (PALT)?

Answer: There exists a paradox of PALT, described in Chapter III, that has many Navy field contracting organizations maintaining PALT within acceptable standards, while growing levels of WIP become older. PALT can be used to determine if WIP is aging, as seen in the Chapter IV decision rule.

6. What are the effects of a level of WIP that is not optimal on the Navy field contracting organization and it's customers?

Answer: WIP that becomes too large and too old will overwhelm the organization's ability to carry out its mission, as discussed in Chapter I. The organization will have to resort to extraordinary measures to be able to continue to serve its customers. The customers will not receive timely, quality support as their purchase orders continue to age in an expanding WIP. Mission readiness of the customers will ultimately suffer.

E. RECOMMENDATIONS FOR FURTHER RESEARCH

1. It is recommended that more years of WIP data be sampled and that further regression analysis be conducted in an attempt to develop more sophisticated models that can accurately predict WIP.

2. Computer programs could be developed that will emulate the input/output process of the small purchase contracting system. Then levels of inputs and outputs could be varied to test the effect on WIP. New indicators can be developed from these tests.

3. It is recommended that the question of what management actions are required and/or appropriate when WIP is not optimal be analyzed.

F. SUMMARY

Managers must monitor and address the WIP situation at their Navy field contracting organizations. The two part decision rule developed in Chapter IV is a viable tool to help managers determine if action is necessary.

APPENDIX

This appendix presents the regression models and model validations for a representative NRCC, NSC, and ICP.

The model presented in Table 1 is the six factor (independent variable) model for a NRCC. The abbreviations for the independent variables in the appendix are: (1) "recs" for monthly receipts, (2) "cmpltns" for monthly completions, (3) "mn/hrs" for man hours per month, (4) "prod" for monthly productivity, (5) "PALT" for monthly procurement administrative lead time, and (6) "crwdys" for crew days.

The assumptions of the regression model that must be checked for each model presented are: (1) the error terms are normally distributed; (2) the error terms are uncorrelated; and (3) the error terms have the same variance (multicollinearity is not severe). The first assumption is checked through a null hypothesis that states the error terms are normally distributed. First, normal scores are calculated with the NSCORES command in MINITAB. Then these scores are correlated with the standardized residuals [Ref. 11:p. 819]. The critical value for this hypothesis, at a 95% confidence level with n = 29, is approximately .963. If the correlation between the expected standardized residuals (the normal scores) and the standardized residuals is greater than .963, the null hypothesis can not be rejected. In this model the

TABLE 1

6 FACTOR NRCC MODEL

The regression equation is
wip = 229 - 1.06 recs + 1.22 cmpltns - 0.329 mn/hrs - 123 prod - 18.7 palt
+ 198 crwdys

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	228.8	351.7	0.65	0.522	
recs	-1.06204	0.05116	-20.76	0.000	4.5
cmpltns	1.2151	0.1122	10.83	0.000	22.8
mn/hrs	-0.3286	0.2235	-1.47	0.156	17.4
prod	-122.7	176.4	-0.70	0.494	16.8
palt	-18.722	1.820	-10.28	0.000	1.6
crwdys	198.240	8.845	22.41	0.000	2.9

s = 143.4 R-sq = 98.4% R-sq(adj) = 97.9%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	6	27149968	4524994	220.00	0.000
Error	22	452496	20568		
Total	28	27602464			

SOURCE	DF	SEQ SS
recs	1	4906284
cmpltns	1	8907782
mn/hrs	1	2837997
prod	1	158397
palt	1	7271
crwdys	1	10332235

Unusual Observations

Obs.	recs	wip	Fit	Stdev.Fit	Residual	St.Resid
5	3956	3230.0	2940.9	50.5	289.1	2.15R

R denotes an obs. with a large st. resid.

Durbin-Watson statistic = 1.63

MTB > nscores c45 c50
MTB > corr c45 c50

Correlation of C45 and C50 = 0.980

MTB > plot c45 c50

```
          -                                                    *
  C45     -                                                *
          -
          -
      1.2+                                             *
          -                                       * **
          -                                     **
          -                                   **
          -                          *******
      0.0+
          -                         *
          -                        *
          -                    ***
          -
     -1.2+                  * *
          -       *  *  **
          -  *
           --------+---------+---------+---------+---------+--------C50
                -1.60     -0.80      0.00      0.80      1.60
```

correlation value is .980, so the error terms are assumed to be normally distributed.

The test for the second assumption, uncorrelated error terms, is based on the Durbin - Watson (DW) test statistic. This statistic is used to test for first order autocorrelation among the error terms only [Ref. 11:p. 819]. The test bounds for the 95% confidence level, with n = 29 and 6 independent variables, are a DW lower value of .98 and an upper value of 1.94. The DW statistic for this first model is 1.63. This value lies within the test region and so is inconclusive.

The test for the third assumption, error terms with the same variance, is based on the Variance Inflation Factor (VIF) for the independent variables. This tests for the degree of multicollinearity that exists in the model. Multicollinearity is considered severe when the maximum VIF is greater than 10, or the average of the VIFs is considerably larger than 1. This model has a maximum VIF of 22.8, and therefore violates the third assumption.

The next model, presented in Table 2, is a four factor model for the same NRCC. The independent variables selected were receipts, completions, man hours, and crew days. The correlation of the standardized residuals with the expected standardized residuals is .956, which is less than the critical value of .963. However, since the plot of the expected standardized residuals looks like a line, and because regression is robust to nonnormality of error terms, the

TABLE 2

4 FACTOR NRCC MODEL

The regression equation is
wip = - 680 - 0.871 recs + 1.10 cmpltns + 0.069 mn/hrs + 154 crwdys

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	-679.8	228.1	-2.98	0.006	
recs	-0.8709	0.1085	-8.02	0.000	3.8
cmpltns	1.1001	0.1004	10.95	0.000	3.4
mn/hrs	0.0689	0.1739	0.40	0.695	2.0
crwdys	154.48	17.72	8.72	0.000	2.1

s = 330.9   R-sq = 90.5%   R-sq(adj) = 88.9%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	4	24974560	6243640	57.02	0.000
Error	24	2627891	109495		
Total	28	27602448			

SOURCE	DF	SEQ SS
recs	1	4906284
cmpltns	1	8907782
mn/hrs	1	2837997
crwdys	1	8322508

Unusual Observations

Obs.	recs	wip	Fit	Stdev.Fit	Residual	St.Resid
12	4120	2447.0	2953.5	233.9	-506.5	-2.16R
29	1470	1425.0	2296.5	163.5	-871.5	-3.03R

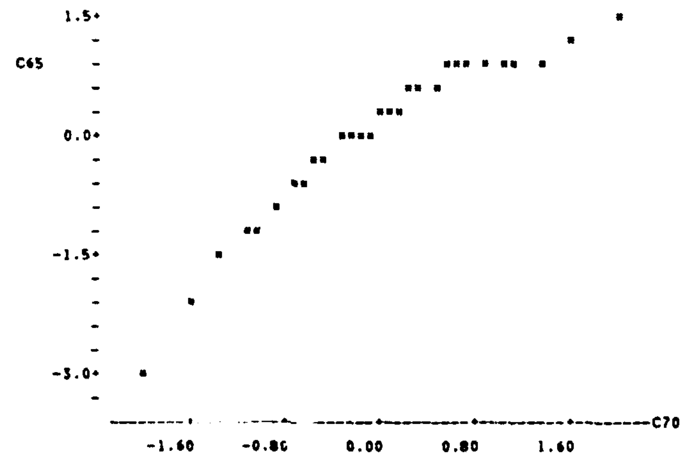
R denotes an obs. with a large st. resid.

Durbin-Watson statistic = 0.58

```
MTB > nscores c65 c70
MTB > corr c65 c70
```

Correlation of C65 and C70 = 0.956

```
MTB > plot c65 c70
```



assumption is validated. The uncorrelated error terms assumption is violated (DW statistic of .58) and must be corrected. The degree of multicollinearity appears acceptable.

The six factor model for an NSC in Table 3 shows all three assumptions of the regression model have been violated. These violations have to be corrected if the model is to be made

TABLE 3

6 FACTOR NSC MODEL

The regression equation is
wip = 19938 - 1.02 recs + 2.81 cmpltns - 2.50 mn/hrs - 13189 prod + 9.8 palt + 418 crwdys

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	19938	20436	0.98	0.340	
recs	-1.0193	0.1094	-9.32	0.000	1.5
cmpltns	2.811	1.666	1.69	0.106	399.1
mn/hrs	-2.499	2.769	-0.90	0.377	283.5
prod	-13189	12302	-1.07	0.295	220.2
palt	9.81	14.93	0.66	0.518	2.5
crwdys	418.11	16.42	25.46	0.000	1.7

s = 818.7 R-sq = 97.9% R-sq(adj) = 97.3%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	6	674149632	112358272	167.63	0.000
Error	22	14745838	670265		
Total	28	688895232			

SOURCE	DF	SEQ SS
recs	1	43456928
cmpltns	1	2159163
mn/hrs	1	84111920
prod	1	12490218
palt	1	97482464
crwdys	1	434448896

Unusual Observations

Obs.	recs	wip	Fit	Stdev.Fit	Residual	St.Resid
1	11735	10056	11778	496	-1722	-2.64R
2	9947	13868	15533	526	-1665	-2.65R

TABLE 3 (CONTINUED)

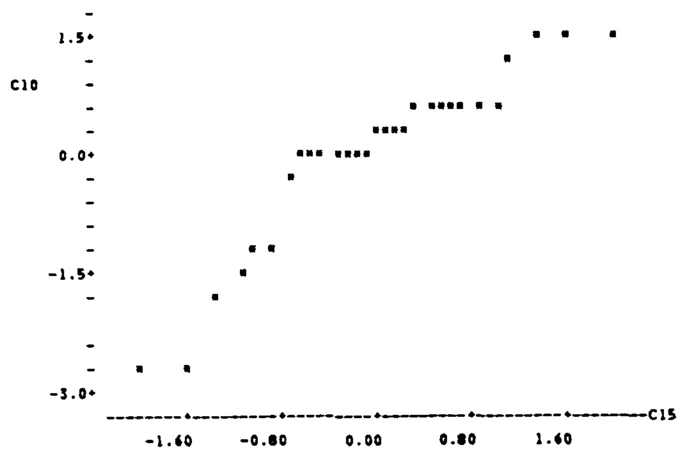
```
R denotes an obs. with a large st. resid.

Durbin-Watson statistic = 0.81

MTB > nscores c10 c15
MTB > corr c10 c15

Correlation of C10 and C15 = 0.944

MTB > plot c10 c15
```



acceptable. The correlation value of the standardized residuals is .944, which is less than the critical value. The DW statistic is .81, which is less than the lower test limit. Finally, multicollinearity is severe, with the largest VIF being 299.1.

A three factor model for the same NSC, based on productivity, PALT, and crew days , produced better results in Table 4. The error terms appear normally distributed. The DW statistic is 1.57, making the test inconclusive for uncorrelated error terms. The degree of multicollinearity is acceptable.

TABLE 4

3 FACTOR NSC MODEL

The regression equation is
wip = - 873 + 1181 prod + 85.4 palt + 331 crwdys

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	-873	3596	-0.24	0.810	
prod	1181	2525	0.47	0.644	1.8
palt	85.41	28.88	2.96	0.007	1.9
crwdys	331.33	28.70	11.54	0.000	1.0

s = 1850   R-sq = 87.6%   R-sq(adj) = 86.1%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	3	603350528	201116832	58.78	0.000
Error	25	85544912	3421796		
Total	28	688895232			

SOURCE	DF	SEQ SS
prod	1	70201904
palt	1	77195488
crwdys	1	455953152

Unusual Observations

Obs.	prod	wip	Fit	Stdev.Fit	Residual	St.Resid
1	1.69	10056	14814	810	-4758	-2.86R
8	1.76	21859	18342	697	3517	2.05R
12	1.83	8632	12006	1067	-3374	-2.23R

R denotes an obs. with a large st. resid.

Durbin-Watson statistic = 1.57

MTB > nscores c20 c25
MTB > corr c20 c25

Correlation of C20 and C25 = 0.968

MTB > plot c20 c25

```
         -
         -                                                     *
      1.6+                                                *
         -                                          **  *
 C20     -                                        *
         -                                     **
         -                                 * **
      0.0+                             ****
         -                      *** ****
         -                 ** * *
         -
         -              *
     -1.6+
         -
         -           *
         -
         -       *
             --------+--------+--------+--------+--------+--------C25
```

The six factor model for an ICP also violates model assumptions as shown in Table 5. While the error terms appear normally distributed, there are indications of correlated error terms (DW statistic is .85). Also, multicollinearity appears severe as the largest VIF is 25.9.

TABLE 5

6 FACTOR ICP MODEL

The regression equation is

wip = - 5807 - 0.486 recs + 1.02 cmpltns + 0.829 mn/hrs + 1756 prod + 11.2 pelt + 111 crwdys

Predictor	Coef	Stdev	t-ratio	p	VIF
Constant	-5807	3063	-1.90	0.071	
recs	-0.4858	0.4650	-1.04	0.307	3.0
cmpltns	1.023	1.344	0.76	0.455	21.0
mn/hrs	0.8291	0.7523	1.10	0.282	12.5
prod	1756	3579	0.49	0.628	25.9
pelt	11.20	12.89	0.87	0.394	2.0
crwdys	111.11	20.51	5.42	0.000	1.6

s = 1159   R-sq = 80.4%   R-sq(adj) = 75.1%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	6	121374720	20229120	15.07	0.000
Error	22	29536752	1342579		
Total	28	150911472			

SOURCE	DF	SEQ SS
recs	1	24359808
cmpltns	1	40788400
mn/hrs	1	11622938
prod	1	958218
pelt	1	4250358
crwdys	1	39394976

Unusual Observations

Obs.	recs	wip	Fit	Stdev.Fit	Residual	St.Resid
8	3434	10184	8588	1045	1596	3.18RX
14	1199	9769	10746	1084	-977	-2.39RX
23	3405	7723	9900	442	-2177	-2.03R

R denotes an obs. with a large st. resid.

X denotes an obs. whose X value gives it large influence.

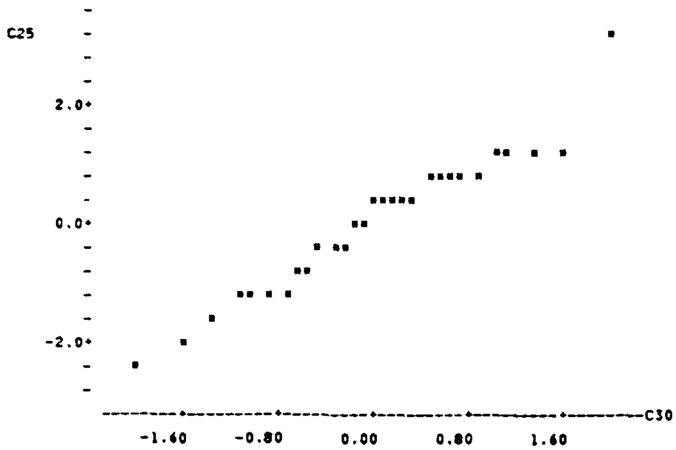
Durbin-Watson statistic = 0.85

TABLE 5 (CONTINUED)

```
MTB > nscores c25 c30
MTB > corr c25 c30

Correlation of C25 and C30 = 0.981

MTB > plot c25 c30
```



The error terms appear to be normally distributed in a two factor model for the ICP (completions and crew days) shown in Table 6. However, there appears to be correlated error terms (DW statistic is .58). The VIFs indicate that the level of multicollinearity is acceptable.

TABLE 6

2 FACTOR ICP MODEL

SOURCE	DF	SEQ SS
cmpltns	1	62274288
crwdys	1	48436288

Unusual Observations

Obs.	cmpltns	wip	Fit	Stdev.Fit	Residual	St.Resid
14	4871	9769	10347	1025	-578	-0.82 X
23	2802	7723	10653	314	-2930	-2.44R

R denotes an obs. with a large st. resid.
X denotes an obs. whose X value gives it large influence.

Durbin-Watson statistic = 0.58

```
MTB > nscores c35 c40
MTB > corr c35 c40
```

Correlation of C35 and C40 = 0.985

```
MTB > plot c35 c40
```

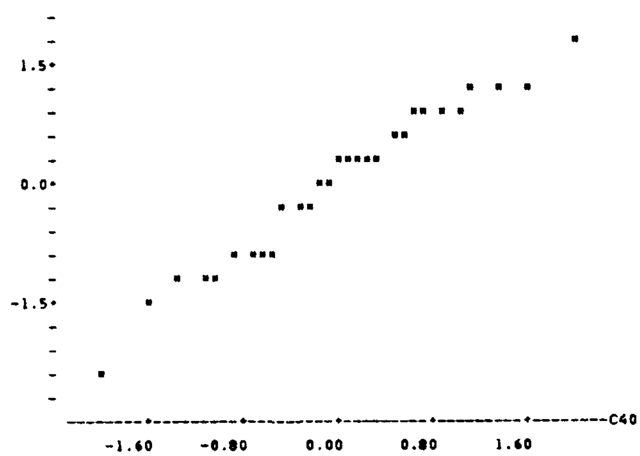


TABLE 6 (CONTINUED)

```
MTB > regr y c1 on 2 c8 c16 store c35;
SUBC> dw;
SUBC> vif.

The regression equation is
wip = - 2038 + 1.62 cmpltns + 100 crwdys

Predictor        Coef       Stdev    t-ratio         p        VIF
Constant        -2038        1352      -1.51     0.144
cmpltns        1.6189      0.3220       5.03     0.000        1.0
crwdys         100.08       17.88       5.60     0.000        1.0

s = 1243        R-sq = 73.4%     R-sq(adj) = 71.3%

Analysis of Variance

SOURCE        DF          SS          MS         F        p
Regression     2   110710576    55355280     35.80    0.000
Error         26    40200880     1546187
Total         28   150911456
```

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   Naval Postgraduate School
   Monterey, CA 93943-5000

8. LT John F. Qua — 1
   4533 Biscayne Dr.
   Virginia Beach, VA 23455